Mobile Robot Deployment in the Context of WSN

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Chapter 1

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The advances in mobile robotics allow us today to add the mobility concept into many different classes of wireless sensor networks (WSN) or wireless sensor and actuator networks (WSAN) applications. The deployment of mobile sensors is possible and useful in many application scenarios, ranging from the environmental monitoring, e.g., volcano activity, dispersion of fire, pollutants or gas plumes, and public safety applications (event or object surveillance), to the industry (structure and machinery health) and military applications (automated warfare, land mine detection). Manual sensor deployment represents a rather difficult task to achieve in such type of applications due to various reasons that will be discussed in this chapter. The use of mobile agents, i.e., robotic platforms equipped with sensory and motion capabilities, allows us to overcome these difficulties by deploying the sensor network in a random manner and applying the self-repositioning of self-deploying techniques.

1.1 Notions of mobile robot deployment

1.1.1 *Sensor network deployment*

The notions of *deployment* and *deployment objective* are hard to define since they depend on the actual application of the WSN/WSAN. Furthermore, the concept of *deployment quality* strongly depends on the deployment goals, sensor, and environment characteristics. Indeed, different deployment solutions can be envisaged in the case of sensors with limited communication and movement capabilities, or the absence of knowledge regarding the deployment environment. In other words, the quality of the deployment is not comparable in the case of mobile sensors with total knowledge of the environment and the availability of the absolute localization techniques, than in the case of absence of any localization technique followed by the completely unknown deployment environment. Bearing in mind that the majority of the applications focuses on a certain type of event (or a set of events) monitoring and data acquisition, the deployment can be referred to as the process of optimally placing a group of sensors (static and/or mobile) in an environment containing the events of interest. In the context of environmental monitoring, the deployment quality will notably depend on the environment covered area, deployment speed, and energy consumption, just to name a few.

In general, the sensors are usually deployed in a random or deterministic manner. Former are hardly feasible in any other situation than the small network deployed in the known environment. The necessity of larger sensor networks in an unknown environment leaves us with the random deployment as the only choice. The random deployments in an unknown environment is usually done by scattering the sensors over an area of interest, such as volcano or forest, from an aircraft. As expected, certain number of sensors deployed in such a manner will not be usable due to failures caused by the aircraft scattering. In order to guarantee the quality of such a deployed network (notably regarding the covered area), the number of sensors deployed must be greatly larger than the optimal number, which increases the overall costs of the network.

1.1.2 *Sensor mobility*

A way to improve the deployment quality in terms of coverage is to introduce the mobility capabilities into the network. In the case of an initial random deployment, static nodes could be replaced with mobile substitutes, which could increase the cost of the network, however, the deployment quality would increase as well. Another method of introducing mobility into the WSN is the addition of a few mobile robots (not necessarily with sensing capabilities) that are used to displace the static sensors, thus increasing the deployment quality.

Including the robot mobility in the WSN deployments allows us the following:

- the possibility to resolve problems that could appear in the network that are not solvable by static nodes,
- increasing the network robustness by automated sensor node replacements,
- the adaptability to unknown or dynamic environments,
- increasing the speed of data processing and routing through the use of parallelism.

There are three major types of mobility that are considered in the context of WSN/WSAN:

(1) *Static (immobile) WSN.* In this first case, the sensors in the network do not possess any kind of locomotion or displacement capability. Furthermore, there are no entities that could interact with or displace sensors in the network. This type of WSN is the most widespread and used in most applications worldwide.
(2) *Assisted mobility.* This second type of mobility assumes a sensor network com-

posed of static sensors that are unable to move autonomously. However, these sensors are usually mounted on different types of mobile agents that provide them with mobility. These moving agents depend on the specific application and their moving pattern is not controllable, however it can be modeled in a certain way. Examples of this type of mobility are the sensors mounted on vehicles, animals, or people [Palmer *et al.* (2004); Liu *et al.* (2013)].

(3) *Controlled mobility.* Finally, the third type of sensors mobility assumes that the network is entirely or partly composed of mobile sensors (mobile robots) that can be manually or self-controlled. This type of mobility allows us to increase the deployment quality in a way that suits the best to the user of the network. Controlled mobility has received much attention in recent years due to the ever expanding possibilities for different applications that were not possible beforehand (notably area exploration and rescue missions).

In this chapter, we focus our attention on the controlled mobility, i.e., the third type of mobility, and we will refer to it in the remainder of the chapter simply as *mobility.*

1.1.3 *Deployment of multi-robot systems in the context of WSN*

By introducing more that one mobile agent with or without sensing capabilities in the sensor network, the WSN may be observed from the point of view of multi-robot systems (MRS). MRS are nowadays used in wide variety of cases, including the scientific, environmental, industrial, and military applications. All of these applications require the high deployment quality in the means of covered area, speed, and energy used which is generally achieved thanks to the carefully chosen controlled mobility technique, which still represents a challenging task.

All the approaches to sensor deployment that include controlled mobility can be classified into two deployment schemes: centralized and distributed deployments. The centralized approach assumes the existence of a central entity that is not necessarily a part of the set of mobile sensors. The role of the central entity in this type of deployment techniques is to collect all the necessary information about all the sensors in the network and the deployment environment itself, process this information regarding the goal of the deployment, choose the optimal positions for each sensor in the network, and finally, direct each individual sensor towards its future destination. This type of approach can achieve excellent results in the static environment, since the optimization algorithms can be applied in order to achieve the optimal deployment. However, the necessity of the global network information acquisition imposes high computational cost in energy, time, and storage space, that collides with the concept of WSN composed of cheap sensors with limited processing power. Furthermore, due to the centralized approach depending on central entity, the complete network is dependent on the errors and failures that can happen in the central entity, which makes the network highly vulnerable. Finally, the scalability of the network in this case represents another huge problem, since the central entity has to manage ever increasing amount of information in real time. The aforementioned problems, together with the dynamics in the most practical environments that increase the complexity of the computation and communication, make the centralized approach infeasible in most practical applications.

On the other hand, the distributed approach easily copes with the problems of the dynamic and unpredictable environments, as well as the problem of scalability, by allowing each robot to calculate its own behavior and mobility pattern depending on the perceived local neighborhood and environment information. In this manner, the computation complexity is reduced to a limited set of locally perceivable neighboring sensors, whatever the size of the complete network is. The goal of the distributed deployment techniques is to combine all the movement decisions that are brought locally and combine them in order to approach the optimal solution achievable by the centralized approach. The drawback of the distributed approach is that the lack of complete knowledge makes impossible to achieve the optimality. However, bearing in mind the environment conditions in practice, followed by the absence of scalability and computational complexity issues, in this chapter we focus our attention only on the distributed approaches to multi-robot WSN deployments.

1.1.4 *Network connectivity problem*

Maintaining the connectivity among the sensors in the network is one of the essential tasks during the deployment (Abbasi *et al.*, 2009; Ghosh and Das, 2008; Zhu *et al.*, 2012). By assuming the distributed approach to the deployment, and thus assuming the localized and constrained knowledge of the network, it is impossible to achieve the optimal (or locally optimal) deployment if the sensors in the network do not form a connected graph. Therefore, it is usually assumed that the set of sensors form a connected network, with tendency to preserve the connectivity at bootstraps all along the deployment procedure and the network lifetime.

In the context of the communication graph that represents the WSN, the connectivity maintenance problem is essentially the problem of moving the sensors in such a way to avoid disconnections in their communication graph. The basic idea that underlies every connectivity preservation technique is to restrain the movements of each mobile sensor depending on the corresponding communication graph. In the general case, the introduced constraints are based on the one-hop communication link and they continuously depend on the sensors' positions. The optimal connectivity preservation technique could be defined as the technique where movement constrains are "loose" enough to minimally constrain the sensor motion.

1.1.5 *Generalized robot deployment algorithm*

All the different deployment approaches that we examine in this chapter and that depend on the specific application of WSN, can be described with one general deployment scheme with a rather simple structure (Fig. 1.1). As we adopted the distributed nature of the deployment, the scheme is iterative and comprises three essential parts: neighborhood discovery, movement target computation, and movement towards the computed target point. In the neighborhood discovery part, the robot transmits its own position and receives the positions of neighboring robots in the deployment field. This information is used in order to construct the communication and sensing graph based on some graph reduction technique, for example, Minimal Spanning Tree, Gabriel Graph, and Relative Neighborhood Graph. The second part of the scheme employs different probabilistic or geometrical techniques to choose the best potential displacement target point while applying the connectivity preservation constraints. Finally, the third part executes the movement towards the selected point. Further details about each part of the generalized deployment scheme depend on the sensor type, environment characteristics and the application specifications.

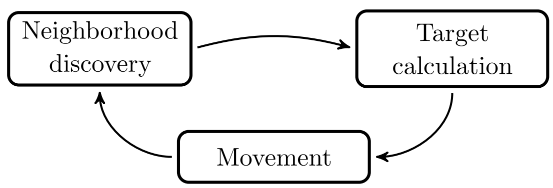


Fig. 1.1 Generalized robot deployment algorithm.

In the remainder of the chapter, we discuss the coverage problem in the WSN (Section 1.2), sensor deployment approaches (Section 1.3) and techniques (Section 1.4), followed by the discussion on different types of mobile robots in the context of WSN (Section 1.5). We discuss some open issues regarding the robot deployment in the Section 1.6 and conclude the chapter in Section 1.7.

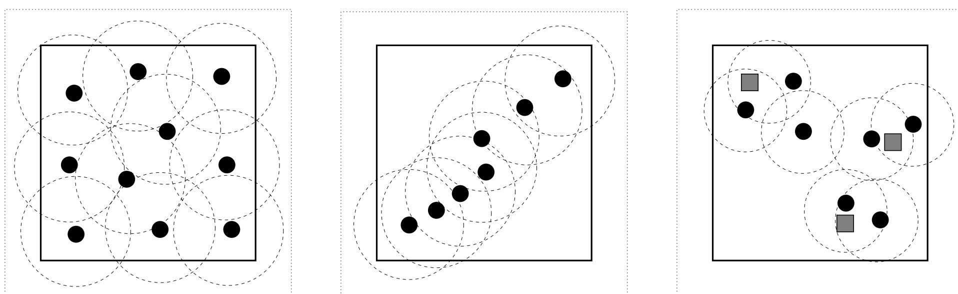
1.2 Coverage problem

The main task in WSNs is to monitor a given target and to transmit cooperatively the collected data over the network to a main location, therefore, the nodes must be able to capture every event about the specific target. Hence, how well a target is sensed by a WSN is an issue called coverage. A target is covered when it is within the sensing range of at least one sensor. The quality of the network is attached to the coverage degree and is often used as a performance metric as well.

The coverage requirements depend directly on each particular coverage problem (Fan and Jin, 2010; Tezcan and Wang, 2007). In general, the coverage problems are classified according to their ultimate goal into three categories: full coverage, barrier coverage, and sweep coverage.

1.2.1 *The full coverage problem*

The full coverage problem is often known as blanket coverage or region coverage problem (Bartolini *et al.*, 2009; Savkin *et al.*, 2012). This problem arises when the objective is to cover a whole field of interest (FoI), i.e., every point within the field must be sensed by at least one node. In Figure 1.2(a), we illustrate the full coverage problem. One example of WSN applications presenting a full coverage problem is in a vineyard, where we have a big field and the sensors must collect information about, for example, temperature or humidity.



(a) Blanket coverage (b) Barrier coverage (c) Sweep coverage

Fig. 1.2 Robot deployment coverage problems.

1.2.2 *The barrier coverage problem*

The concept of barrier coverage differs substantially from the concept of full coverage (Kumar *et al.*, 2007). The goal of full coverage is to deploy a set of sensors to cover an entire zone meanwhile the border coverage aims to detect intrusions in or across the target zone. Therefore, the sensors are deployed only through the crossing paths of FoI in order to reduce the possibility of a given intruder crossing the field undetected. Figure 1.2(b) represents an example of barrier coverage, where the nodes are spread over a line. A key example is a border line, where there is a huge effort to detect any crossing violation. For this example, the sensor should be deployed in a line to surround the field of interest. In particular, it is an interesting proposal to work jointly with sensors and cameras to detect any unauthorized crossing.

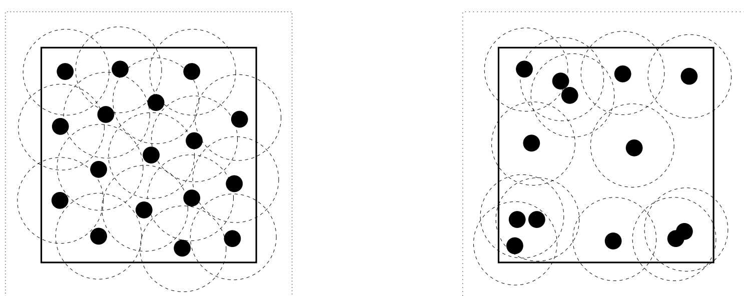
1.2.3 *The sweep coverage problem*

In general, when the sensors are deployed to solve the FoI or barrier problems, they remain static at their positions (Li *et al.*, 2011). However, the coverage strategy changes when the network must cover only a few Points of Interest (PoI) or targets. These specific PoI may be static or dynamic in the time, i.e., the points that are of interest at a given time can change dynamically after a while. This means that the sensors must be redeployed in order to cover the new PoI. Therefore, the concepts of robotics are very important in the context of sweep coverage to provide the sensors with mobility capabilities. Figure 1.2(c) illustrates a field with several PoI inside, the sensors are deployed to cover a few specific points leaving the rest of the field uncovered.

1.3 Deployment approaches

1.3.1 *Deterministic deployment*

The sensors' positions are set up before the actual deployment following a predefined shape, as a diamond for example. Taking the application into account, the sensors are deployed uniformly over the target region or with a weighted distribution to cover a certain number of targets. An example of the deterministic approach is a grid-based deployment where the nodes are equidistantly separated according to a grid shape. Figure 1.3(a) depicts a deterministic deployment, the nodes are even placed over the field.



(a) Deterministic (b) Random

Fig. 1.3 Robot deployment approaches.

1.3.2 *Random deployment*

A deterministic deployment for many applications is unpractical or simply not possible to do. In these cases, the sensors can be deployed randomly, e.g., dropping the sensors from an airplane. Hence, the localization of the nodes is unknown before the deployment. In general, it is possible to use a stochastic distribution, such as uniform, Gaussian, or Poisson to model the sensor distribution. Figure 1.3(b) depicts a random deployment, where the nodes are randomly placed over the field.

1.3.3 *Static*

Once the sensors are placed, they remain at the same position. Generally, the deployment algorithms consider static nodes since they are cheaper than mobile ones. The static deployment may be at the same time random or deterministic.

1.3.4 *Dynamic*

A dynamic deployment assumes that some or all sensors have mobility capabilities. Mobility allows the deployment of nodes on-demand, controlling the movement to obtain particular network topologies, specially in unknown environments. This scheme, also, represents the possibility of *re-deploy* the network in case that the environment's conditions change [Zhang *et al.* (2009)].

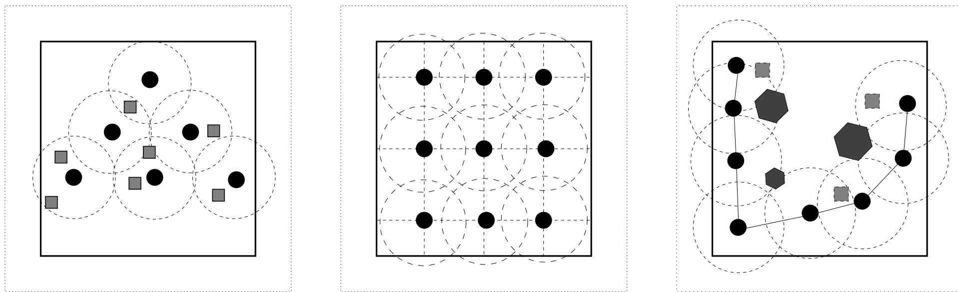
Usually, the deployment algorithms proposed in the literature consider a subset of the requirements presented above for particular scenarios. For example, in case of blanket coverage of a building it is easy to envision the usage of a deterministic algorithm. Such an algorithm should optimize the number of nodes, the distance between them, and the coverage range. Conditions change when there is no any a priori knowledge about the environment, for example within forest. In such a case, some areas of the field could be not covered at all, several nodes could be too close or too far from each others. Hence, the random topology may not fulfill the coverage and connectivity requirements. In this latter case, it is possible to use mobile nodes to redeploy them and then guarantee the coverage.

1.4 Field coverage optimization

The result of the deployment phase has close implications with the algorithms used to optimize the coverage. Therefore, the algorithm design must consider, both coverage and deployment in order to optimize the network performance [Wang *et al.* (2009)].

1.4.1 *The pattern-based technique*

In order to localize the PoI, the sensors are deployed in a predefined regular pattern, such as spiral, hexagon, circular, or triangle. Once the sensors are deployed following the pattern, their final positions are computed either by considering the global coverage or by using a mobile sink sensor that acts as a facilitator to help other sensors to find their final position. A main drawback of this type of techniques is that they do not provide connectivity during the whole deployment procedure. In Figure 1.4(a), we present an example of pattern-based coverage, where the nodes are deployed following a triangle form.



(a) Pattern-based (b) Grid-based (c) Virtual force-based

Fig. 1.4 Robot deployment techniques.

1.4.2 *The grid quorum-based technique*

The field is divided into several small grids forming cells. Each cell has a load depending on the number of sensors inside the cell. Therefore, the coverage and connectivity are a function of the grid's size. Thus, the sensors must move in order to balance the cells' load. Figure 1.4(b) depicts the grid quorum coverage, all the nodes are even placed all across the field creating a well-defined grid.

1.4.3 *The virtual force-based technique*

The virtual force technique is based on the concept of electromagnetic particles, where the particles attract or repel each other according to the particles characteristics. Mapping the concept to sensor networks, the preferential coverage areas work as attraction forces, meanwhile, the obstacles work as repulsion forces. Hence, these forces are computed based on the sensor's neighborhood to allow the computation of the sensor's next movement. Figure 1.4(c) illustrates a field with several PoI inside, the sensors are deployed avoiding the obstacles and preserving the connection with the sink node.

Special algorithms are required after the deployment to guarantee the coverage and connectivity in the network. Such algorithms, centralized or distributed, manage problems, such as, connectivity preservation, saving energy, and range adjustment that help to optimize the network performance.

1.5 Mobile robots in the context of WSN

In this section, we introduce different types of mobile robots that could be used as an integral part of the wireless sensor network for a specific application and depending on the deployment area characteristics. Furthermore, we discuss some problems of robot and sensor interactions withing the network, followed by the set of typical robotic sensor network applications.

1.5.1 *Mobile robots as autonomous vehicles*

Despite being out of the scope of this chapter, it is worth noting that the term *mobile* robot could represent any type of robot with movable parts that is capable of changing its position in a certain way. That notion includes the wide range of industrial robots used in production lines. However, in the context of WSN, we focus our attention only on mobile robots that represent autonomous vehicles whose movements are not limited by their physical size. Hence, mobile robots as autonomous vehicles can be used to explore unknown environments and perform a variety of functions that would normally been performed by humans. They are classified in three large groups depending on their operating environment:

(1) *Ground vehicles (land-based robots).* This is the largest group of mobile robots that is widely used in different sorts of applications due to its relative simplicity of construction and intuitive operating mode.
(2) *Aerial vehicles (flying drones).* The development of this group of robots is under expansion notably due to the specific characteristics of the deployment medium. The use of flying drones allows us to avoid the problems of physical obstacles in the deployment field simply by flying over them, backed up by the increased speed of deployment in comparison with the land-based robots. This type of mobile robots is often used for the applications of area surveillance and target detection/tracking.
(3) *Marine vehicles (aquatic robots).* This group of robots introduces a specific set of challenges due to the deployment environment characteristics. Being deployed in the water, these robots face two problems: the problem of communication in the aquatic medium and the problem of localization since the global localization techniques are not available if the robot is submerged under water. A significant amount of research is being done in recent years in order to find a satisfying technique of communication, via sound waves rather that the electromagnetic waves, and localization, landmark based instead of global positioning, (see also Chapter **??**).

1.5.2 *Mobile robots and the interaction with WSN*

We have already mentioned that the random deployment of static WSN requires a number of sensors that is greater than optimal, which impacts the overall deployment cost. One of the solutions to this problem is the conjunction of a classic static WSN with a set of mobile nodes (Lambrou and Panayiotou, 2009). In this context, the role of mobile robots is twofold. First, the set of mobile robots serves as mobility provision agents. In this case, the goal is to physically displace already deployed static sensors in the deployment field and thus increase the deployment quality. However, it cannot be guaranteed that in every WSN application, such approach would improve the quality of the deployment while minimizing the deployment costs. As stated before, this problem is strongly dependent on the specific application specifications and, above all, on the deployment environment characteristics. An example of infeasible interaction of mobile robots with static WSN is the WSN for the seismic activity monitoring that is deployed on the ocean floor. Such hostile deployment environment rules out the implementation of a multi-robot system capable of providing the sensors with mobility. In such and similar cases, it is worth considering the trade off between the cost of introducing the mobility versus the additional set of static nodes with the accent put on the improved data acquisition protocol that could achieve better results and increase deployment quality (Heidemann *et al.*, 2012).

The second role of the mobile robots in the interaction with the WSN is automated sensor network servicing. Although not directly involved in sensing and acquisition tasks, a set of mobile robots can influence the deployment quality by replacing damaged or discharged sensors with working replacements, or even behaving as a mobile recharging station, thus prolonging the lifetime of the network (Mei *et al.*, 2007; Sheu *et al.*, 2008; Xie *et al.*, 2012). The sensor node servicing by a group of mobile robots is a complex problem and may be observed as one deployment problem within another – the application of the WSN is the environmental information acquisition, while the application of the set of servicing robots is both the acquisition of the information regarding the sensor network and the servicing decision and schedule problem.

1.5.3 *Applications of mobile robotic networks*

Generally speaking, there are two classes of applications in which the use of autonomous mobile robots is needed:

- inaccessible or unknown deployment environment inspection (warfare field, structural health monitoring, and machinery inspection (Nikolaus and Martinoli, 2009)),
- and the hazardous environment where the presence of humans can be endangered (minefields, toxic gas leaks, and pollutions source detection (Lochmatter *et al.*, 2007)).

Regarding the first class of applications, the mobile multi-robotic networks play an important role in the field of electronic and visual reconnaissance, deployment field surveillance, target detection, and identification. Most of these applications have a military connotation up to a certain degree, which is understandable since the huge amount of resources are allocated in order to improve the quality and usability of mobile robotic networks. Military applications focusing on security are present in the second class of applications as well, with the applications such as minefield exploration and mine detection, together with chemical, biological, radiological, nuclear, and explosive reconnaissance problems that need to be solved with the help of mobile robotic networks.

One typical example of the robot deployment for such means is presented in [Kantor *et al.* (2003)]. A set of autonomous mobile robotic vehicles is deployed in the building that suffered an attack and therefore represented an unknown environment with unknown number and placement of people inside. The goal given to the set of robots was to explore the ruined building, locate the people inside and to provide the rescuers with the exact information regarding the situation in the building. Needless to say that the speed of the deployment was of the essence and that all the robots had to collaborate in order to save human lives. This example shows that it is possible to achieve fast and reliable autonomous robot deployments in order to tackle the problem that could not be solved in a different way.

1.6 Discussion and open issues

In this section, we discuss some of the common issues in the robotic networks and point out important properties of wireless robotics that should be kept in mind in order to achieve successful mobile robot deployments.

1.6.1 *Communication*

The most important issue in the wireless network is the communication aspect that in this case has its own special characteristics. We can consider two different communication paradigms in this case: direct and indirect communications. The first way of communication is the explicit one, two sensors represented as the sensor nodes in the network can communicate with each other through an established one or multi-hop wireless links. The specific purpose and architecture of a WSN force the sensors to communicate with their neighbors usually only by means of exchanging their position information and transmitting the sensed information towards the data center. However, without loosing of generality, it can be assumed that two sensors can communicate directly via established links.

A second way of communicating is the indirect one – the communication through the signs in the environment. This way of communication is bio-inspired, where instead of creating a direct wireless link, there is no direct communication link that is established, rather the sensors change the deployment environment (by leaving signs, pheromones, etc.) in the way that will be understood by other sensors in the deployment. An example of indirect communication in the set of servicing robots is the communication through messages left at the serviced nodes that can be read by other robots that will pass by. It is worth noting that in this way of communication, there is no need for constant connectivity maintenance, therefore, this type of communication techniques can be used in sparse networks. On the other hand, indirect communication introduces high latency in the network and is not suitable for deployments that require a fast response time.

Another essential problem that arises in the implementation of the robotic wireless networks is due to the wireless channel properties. The wireless communication medium does not have a predictable behavior as the wired channel. This makes the signal strength and the propagation delay highly dependent on the robot hardware, network topology and the properties of the environments (propagation medium, obstacles, etc.). Furthermore, the wireless medium is a broadcast medium, which means that all the nodes in the transmission range of a node transmitting a message, can receive that message, and this poses a problem of unnecessary energy depletion caused by the messages that will be discarded.

In the context of geometry-based deployments, missing short and unexpected long links are common problems, hence, an important issue is the physical link length. The effect of a wireless channel in certain cases makes impossible for two physically close sensors to establish a wireless link. Likewise, in some cases the link can be established even if the distance between two sensors is way beyond the expected maximal communication range. Therefore, the robot deployment becomes a highly complex task if the communication medium properties are taken into account.

These issues, combined with the dynamics introduced in the sensor network that make the network topology change rapidly and unexpectedly, highly affect the availability of communication paths and the quality of the communication.

1.6.2 *Infrastructure based problems*

An integral part of the sensor deployment in most applications is the establishment of the data acquisition infrastructure. The dynamic nature of the robot deployment changes this paradigm in a sense that the network infrastructure must be auto-adaptable to environment conditions. Examples for this are the disaster areas where it is not possible to elect a set of sensors that will play the role of the communication backbone due to the possibility of sensor failures. The complete network should rather be equipped with the mechanisms of overcoming these types of unexpected environment behavior.

Setting up the network infrastructure may seem to be not a so complex task, however, the problems of cost and time to set it up can arise. The cost of the auto-adaptable network infrastructure becomes an obstacle in remote and large construction sites where the robotic network is used for a structure and machinery health monitoring. In most military applications that require fast and reliable response to environmental changes, the network infrastructure reaction time represents one of the major issues.

1.6.3 *Robot robustness, heterogeneity and scalability*

Another major obstacle in the widespread robot deployments is the reliability of mobile robots in the presence of environmental disasters. Robot failures lead to the loss of gathered information and possible network disconnections. These problems could be overcome with the appropriate information routing techniques, however, they do not guarantee that the network will be able to overcome all the problems. In the practical implementations of robotic sensor networks, robots that are used are often heterogeneous, and therefore, prone to different sets of environmental hazards. Information routing protocols usually assume a heterogeneous network of robots, which is not the case in practice. Furthermore, robot robustness is usually examined on the scale of individual robot. In the practical implementations, failures that appear are usually linked to more than one robot that operates in the desired environment, and these failures are sometimes environmentally provoked, meanwhile some other times they are induced by the interaction between the robots. In any case, they are not trivial to detect and overcome.

Standard WSN data acquisition techniques assume a dense sensor network which is still not the case in robotics. The greatest obstacle to achieve in a dense robotic network is the robotic unit price – robotic sensors cannot be considered as cheap sensing devices with limited storage, energy, and processing power (which is astandard assumption in WSN). Due to the sparsity, individual node failures can lead to greater disasters in the networks that could be expected with reasoning inherited from WSN principles.

1.6.4 *Robots, system and sensing model design*

Robot network design generally aims at finding the balance between the simplicity of the individual robotic sensor units and the complexity of the final system that comprises networked robots, but the communication and control flow as well. A number of problems arise due to the lack of understanding of the final application goals and needs, along with the compromise between the highly specialized and generalized modular components used in the construction of the robotic sensors. Modular and reusable components generally reduce the effort and work needed to conceive and implement mobile robots, and in this manner reduce the development costs linked to new component testing. On the contrary, specialized components used in the construction of mobile robots provide the sensor network with the increased suitability and higher performance in the desired application.

Although most of the literature on coverage and connectivity using sensor nodes assume the probabilistic or disk sensing model, the practical implementation issues show that the considered models largely deviate from the reality. Indeed, the practical deployments are environment-dependent and thus cannot be modeled without the detailed knowledge about the deployment characteristics (including the application goal and the environment properties).

1.6.5 *Testing*

The final and fundamental component of any system integration is testing. Robotic networks dedicated for information acquisition applications in the context of WSN, suffer from the same problem that strikes any product in development – the compromise between thorough testing and the necessity to move a designed system to the market quickly. Full system testing is impossible to achieve, above all in the design of mobile robots dedicated for the aforementioned applications, since it is impossible to envisage all the possible situations and hazards that could appear in the real world.

First level of testing is the testing of the used components in the construction of the robotic platform in order to verify their functionality as stated in their specification. When the complete deployment system is integrated, the next level of testing focuses on the functionality of the system itself. This testing phase can take a long period of time in order to ensure the reliability and robustness of the single components integrated in the complex system that is required to fulfill its goals over a long period of time and in various conditions. The last and the critical part of the reliable robotic network is the implementation of the internal self-monitoring techniques that will allow the system itself as well as the individual robots in order to detect, recognize, and solve a set of potential problems that may arise in a real world implementation.

1.7 Conclusion

In this chapter, we discussed the problem of mobile robot deployment by introducing the concept of deployment itself, sensor mobility, and robotic networks. We provided an analysis of different types of deployment techniques and approaches, followed by an analysis of different mobile robot types, the concept of mobile robots in the context of wireless sensor networks, and the set of possible applications for robot deployments. Finally, we concluded the chapter with a discussion on a number of open issues that arise in the real applications and that the robotic sensor network must cope with.

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